PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 14 April 2000 (14.04.00)	
International application No. PCT/CA99/00739	**Applicant's or agent's file reference** 154b-106PCT
International filing date (day/month/year) 10 August 1999 (10.08.99)	**Priority date** (day/month/year) 10 August 1998 (10.08.98)
Applicant WANG, Meng et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

10 March 2000 (10.03.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Pascal Piriou Telephone No.: (41-22) 338.83.38

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●ATENT COOPERATION TREATY●

09/762631

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 154b-106PCT	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/CA 99/00739	International filing date *(day/month/year)* 10/08/1999	(Earliest) Priority Date *(day/month/year)* 10/08/1998
Applicant DIGITAL ACCELERATOR CORPORATION et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      - [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      - [ ] contained in the international application in written form.
      - [ ] filed together with the international application in computer readable form.
      - [ ] furnished subsequently to this Authority in written form.
      - [ ] furnished subsequently to this Authority in computer readble form.
      - [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      - [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).
4. With regard to the **title,**
   - [X] the text is approved as submitted by the applicant.
   - [ ] the text has been established by this Authority to read as follows:
5. With regard to the **abstract,**
   - [X] the text is approved as submitted by the applicant.
   - [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. ______
   - [ ] as suggested by the applicant.
   - [ ] because the applicant failed to suggest a figure.
   - [ ] because this figure better characterizes the invention.
   - [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 99/00739

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T9/40

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BANHAM M R ET AL: "A WAVELET TRANSFORM IMAGE CODING TEHNIQUE WITH A QUADTREE STRUCTURE" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON ACOUSTICS, SPEECH AND SIGNAL PROCESSING (ICASSP),US,NEW YORK, IEEE, vol. CONF. 17, page IV-653-IV-656 XP000467279 ISBN: 0-7803-0532-9 abstract page 654, paragraph 3 ---	1,2,4,7, 8,10,12
A	US 5 764 807 A (SAID AMIR ET AL) 9 June 1998 (1998-06-09) abstract column 5, line 65 -column 6, line 5 --- -/--	1,2,4,7, 8,10,12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 November 1999	03/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	González Arias, P

1

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GIJBELS T ET AL: "AN ASIC-ARCHITECTURE FOR VLSI-IMPLEMENTATION OF THE RBN-ALGORITHM" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON PATTERN RECOGNITION,US,LOS ALAMITOS: IEEE COMP. SOC. PRESS, vol. CONF. 10, page 408-412 XP000166513 ISBN: 0-8186-2062-5 page 410, paragraph 2 -----	6

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 99/00739

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5764807	A	09-06-1998	NONE	

09/762631

PATENT COOPERATION TREATY

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REC'D 16 OCT 2000

WIPO PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

15

Applicant's or agent's file reference 154b-106PCT	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/CA99/00739	International filing date *(day/month/year)* 10/08/1999	Priority date *(day/month/year)* 10/08/1998
International Patent Classification (IPC) or national classification and IPC G06T9/40		
Applicant DIGITAL ACCELERATOR CORPORATION et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 8 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☐ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand 10/03/2000	Date of completion of this report 12.10.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Borotschnig, H Telephone No. +49 89 2399 7459

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

Description, pages:

1-10	as received on	10/03/2000	with letter of	10/03/2000

Claims, No.:

1-12	as received on	10/03/2000	with letter of	10/03/2000

Drawings, sheets:

1/9-9/9	as received on	10/03/2000	with letter of	10/03/2000

2. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application.

☒ claims Nos. 1-4,6-12.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 1-4,6-12 are so unclear that no meaningful opinion could be formed (*specify*):

see separate sheet

☒ the claims, or said claims Nos. 3-4,9-10 are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

see separate sheet

<u>Re Item III</u>

Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. Present **claims 1-4,6-12** are so unclear that no meaningful preliminary examination can be carried out, Article 6 PCT.

2. Since method claims 1-4 parallel apparatus claims 7-11 corresponding claims of different categories will be grouped in the following discussion.

3. As to **independent claims 1 and 7**:

   a) The claims read "A method/an apparatus for encoding <u>and decoding</u> digital still images...". However only activities/means relating to the encoding phase and the subsequent step of transmitting the encoded data are present in claims 1 and 7. (NB: It is noted that independent claim 12 defines "a method of decoding...").

   b) Certain terms/expressions used in the claims are unclear because

      i) they are neither commonly used technical terms nor is their meaning common general knowledge (Rule 10(e));
      ii) the intended meaning of these terms in the present context is not derivable from the claims as no definition based on commonly used or well known terms is given in the claims.

   The following list of affected terms/expressions includes a variety of questions for which the present set of claims fails to provide answers. This fact leaves the skilled reader in a state of doubt as to what are actually the intended mechanisms underlying the invention and how the scope of protection of the present claims should be derived.

   <u>Unclear expression: "setting an initial threshold of significance"</u>,
   Questions: "Significance" of what ? How is "significance" defined/quantified in order to be able to compare it to a threshold ?

Unclear expression: "creating a significance index",
Questions: What is "a significance index" ? How is it used in the context of the present invention and for what purpose ? (The term only appears once in each of the claims 1 and 7).

Unclear expression: "determining an initial list of insignificant blocks",
Questions: Blocks of what ? (raw image data / sub-image data ?)
How is "insignificance" measured ? How are these blocks used in the context of the present invention and for what purpose ? (Again, the term only appears once in each of the claims 1 and 7).

Unclear expression: "forming the list of significant coefficients by encoding a significance map using a quadtree representation".
Questions: Where is the antecedent support for "the list of significant coefficients" ? What is "a significance map" ? How is it obtained ?
How can a "significance map" be encoded using a "quadtree representation" and how does this lead to a list of "significant coefficients" ?

Unclear expression: "recursively reducing the threshold values and repeating the encoding process for each threshold value"
Questions: How does the previously mentioned "initial threshold of significance" relate to the considered plurality of "threshold values" ? What is processed recursively (only the step of reducing the threshold values ?) and what is processed "repeatedly" (the encoding process as a whole including the initial steps of decoding and ordering the raw image data into a hierarchy of multi resolution subimages ?) and when does the recursion/repetition stop ?

Unclear expression: "transmitting refinement bits of significant coefficients"
Questions: What are "refinement bits" ? How are they obtained ? Is this the only information transmitted/needed to encode the image (headers etc.) ?

c) The interrelations of the steps of the method (which are also performed by the apparatus) cannot be understood from claims 1 and 7 because the different (ill defined) quantities are not clearly related to each other: i.e.

it is not clear from the claims what is inputted to the processes, what is processed at what stage of the encoding procedure and which output is passed on to the next stage. In particular it is not clear how the final output is generated from the input and the intermediate results.

4. As to **dependent claims 2-4,6 and 8-11:** Since these claims depend on the unclear claims 1 and 7, respectively, they are also unclear under Article 6 PCT. The following additional violations of the requirements of Article 6 PCT are noted:

5. **Claims 3-4 and 9-10** define the following features in terms of their function: composing a hierarchy of multi resolution sub-images on the basis of a Fourier based transformation and raw image data, respectively. In combination with claims 1 and 7 it can also be understood that this composition has to be such that the encoding method of the present invention compresses the bit stream.

   However, the description and drawings convey the impression that these functions are only carried out in a particular way, namely by a wavelet transformation, and no alternative means are envisaged. For example, the description of Fig. 1a at page 5, lines 28-29 reads "Figure 1a is a graphic illustration of the present invention's three layer wavelet decomposition of the test image Lena".

   Since it is not immediately evident to the skilled person how, e.g. a "Fourier based transformation" might be used (a) to decompose the image into a set of multi-resolution sub-images which are (b) also suitable for a method to produce a compressed bit stream and because the description does neither disclose any indication for doing this nor any way of achieving the desired result the claims cannot be considered to be supported by the description, Article 6 PCT.

6. **Claims 6 and 11** contain the following unclear terms, the latter of which is also lacking antecedent support: "region and resolution channel", "bit budget". In addition, method claim 6 contains references to "the encoder" and "the decoder", i.e. to apparatus aspects of the invention, and contains the expression "comprising the step of a multiplexing protocol" which is grammatically unclear.

7. As to **independent claim 12:**

a) The claim reads "A method of decoding still images to produce a... compressed bit stream...": It is unclear how and why the decoding phase should produce a "compressed bit stream".

b) The expression "decoding the bit stream header" is unclear because (1) "the bit stream header" lacks antecedent support, (2) this feature is not mentioned in the definition of the encoding phase in claims 1,7. Since the decoding phase should actually "undo" the encoding steps, present claim 12 - when taken together with claims 1,7 - is unclear because the set of features of these claims is not harmonized.

c) The following terms lack antecedent support: "the initial threshold values", "the array of initial significant pixels, insignificant bits and wavelet coefficients", "the significance maps", "the significance lists", "the refinement bits", "threshold level", "the wavelet coefficient array", "the inverse wavelet transform".

d) The observations made in the discussion of claims 1 and 7 also apply to claim 12 (with appropriate modifications) : claim 12 lacks clear definitions of the individual, employed expressions and does not explicate the interplay of the different steps. Thus the claim fails to provide enough information for the skilled person to understand how the desired result is produced and how the scope of protection of the claim can be defined.

Re Item VII

Certain defects in the international application

8. The following document is cited in the description of the present application;

   D1: SAID, Amir and PEARLMAN, William: ' A NEW, FAST AND EFFICIENT IMAGE CODER BASED ON SET PARTITIONING IN HIERARCHICAL TREES', IEEE Trans. on Circuits and Systems for Video Technology', Vol. 6, No. 3, June 1996

   In view of the description of the present application it appears that document D1 is the closest considered prior art document.

9. Independent claims 1,7 and 12 are not in the two-part form in accordance with Rule 6.3(b) PCT, with those features known in combination from the prior art document D1 being placed in the preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in the characterising part (Rule 6.3(b)(ii) PCT).

10. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

11. The claims are not numbered consecutively as **claim 5 is missing**, Rule 6.1(b).

12. The reference signs in Fig. 2 are not consistent with the description and Fig.3, (Rule 11.13(l),(m) PCT).

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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G06T 9/40

A1

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(43) International Publication Date: 24 February 2000 (24.02.00)

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(30) Priority Data:
60/096,007 10 August 1998 (10.08.98) US

(71) Applicant (for all designated States except US): DIGITAL ACCELERATOR CORPORATION [CA/CA]; Suite 840, 650 West Georgia Street, Vancouver, British Columbia V6B 4N9 (CA).

(72) Inventors; and
(75) Inventors/Applicants (for US only): WANG, Meng [CA/CA]; 3027 Laurel Street, Vancouver, British Columbia V6B 4N9 (CA). XIONG, Yi [CA/CA]; 328 Louis Riel House, Simon Fraser University, Burnaby, British Columbia V5A 1S6 (CA).

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(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: EMBEDDED QUADTREE WAVELETS IN IMAGE COMPRESSION

(57) Abstract

The invention is a new effective and fast method and apparatus for still image compression. The present invention implements an embedded progressive sorting scheme in a quadtree-like structure. In contrast to zerotree-based methods for wavelet coding, the invented embedded quadtree wavelet (EQW) method exploits the inherent spatial self-similarity within individual layers of the multiresolution decomposition hierarchy. This self-similarity offers higher predictability of the data within the same resolution level, and therefore usually provides a higher performance in seeking a compact code. The computation involved in the EQW method is more efficient than in the zerotree wavelet coding, and the produced bitstream is more robust to channel noise. The present invention can be effectively used for object-oriented shape coding or region coding in image and video compression coding systems.

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EMBEDDED QUADTREE WAVELETS IN IMAGE COMPRESSION

Field of the Invention

The present invention relates generally to image coding, and more particularly to compression and decompression of digital images.

Background of the Invention

The advent of multimedia computing has created an increased demand for high-performance image compression systems. In the last few years, the wavelet transform has become a mainstream, base technology for image compression coding. Wavelet transforms, otherwise known as hierarchical subband decompositions, result in multi-resolution decomposition hierarchy (MDH) representations of the source image as illustrated in Fig. 1. Bit rates lower than 1 bit/pixel can be achieved through the efficient coding of the wavelet transform coefficients generated in the production of the MDH data.

A most important and beneficial characteristic of the wavelet coefficients generated by the transform is that most of the coefficients will possess very small amplitudes that will reduce to zeros after scalar quantization. For many image processing purposes, the importance or significance of a wavelet transform coefficient can be measured by its absolute value in relation to predetermined threshold values. A wavelet coefficient is said to be significant or insignificant, in relation to a particular threshold value, depending on whether or not its magnitude exceeds that threshold. The importance of a set of wavelet coefficients can be collectively ascertained using a "significance map". A "significance map" is a bitmap recording the location of the significant coefficients. A large fraction of the bit budget may be spent on encoding the significance map. Therefore, the compression performance of an image coding system largely relies on its efficiency in coding the significance map.

In U.S. Patent 5412741 J. M. Shapiro disclosed an embedded zerotree wavelet algorithm called "EZW". A more efficient implementation of this invention, called set

partitioning in hierarchical trees or "SPIHT" was disclosed by Said et al. in "A New, Fast, and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees", A. Said and W. Pearlman, IEEE Trans. On Circuits and Systems For Video Technology, Vol. 6, No. 3, June, 1996.

Because of its inherent simplicity, efficiency and competitiveness in performance to most other techniques, EZW-based coding has been considered one of the best in the image compression research community. Further, it has been chosen as a candidate technique for the new generation International Standard for image (JPEG 2000) and video (MPEG 4) coding.

EZW-based coding techniques consist of three basic methodological elements. The first element is the partial ordering of the MDH data by amplitude. By duplicating the ordering information at the decoder, such that the MDH data with larger amplitude will be transmitted first, it is assured that the transformation coefficients carrying a larger amount of information will more probably be available in reconstructing the image. Usually, the partial ordering is performed using a set of octave decreasing thresholds. The second element is the ordered bit plane transmission of refinement bits in order to achieve the embedded quantization. The third element is to make use of the cross, sub-band correlation between the amplitudes of MDH data to code the significance map.

Although the zerotree structure has proven successful in coding MDH data, it is not the only logical exploitation of the data set's inherent regularities. EZW is not the most efficient representation when considering the compactness of the resulting code nor does the completely closed structure of the zerotree method allow for independent or parallel processing. In the case of a zerotree-coded, multi-layer representation of a visual object like an MPEG-4 object, only the base layer can be independently decoded. The decoding of all enhancement layers must rely on the information of previously decoded layers. In other words, the zerotree representation of objects inherently prevents independent decodability. This inseparability also introduces a higher susceptibility to bit errors. A single bit error could potentially, after

interpretation at each succeeding resolution level, lead to decoder derailment. Finally, the closed structure of zerotree representation makes it difficult to add in new coding methods or features.

Summary of the Invention

The present invention is a method of compressing grayscale and color image data with a high degree of compression performance. An objective of the present invention is to provide a compressibly efficient, fast, method and system to code the significance information of the wavelet transform coefficients. A further objective is to provide a method and system of producing a compressed bit-stream that is scalable, region-based accessible, robust to errors, and independently decodable. The present invention provides a logically simple and fast method of coding that possess and a high degree of parallelism that lends itself to hardware implementation. The bit-stream produced by the present system is more robust to bit error than the prior art since all sub-band blocks are encoded independently and errors at one scale will not lead to errors in other scales.

In accordance with an aspect of the instant invention there is provided a method for encoding and decoding digital still images to produce a scalable, content accessible compressed bit stream comprising the steps of decomposing and ordering the raw image data into a hierarchy of multi-resolution sub-images; setting an initial threshold of significance and creating a significance index; determining an initial list of insignificant blocks; forming the list of significant coefficients by encoding a significant map using a quadtree representation; recursively reducing the threshold values and repeating the encoding process for each threshold value; and then transmitting refinement bits of significant coefficients.

In accordance with another aspect of the instant invention there is provided an apparatus for encoding and decoding of digital still images that produces a scalable, content accessible compressed bit stream comprising a means of decomposing and ordering the raw image data into a hierarchy of multi-resolution sub-images; means for setting an initial threshold of significance and creating a significance index; means for

determining an initial list of insignificant blocks; means of forming the list of significant coefficients by encoding a significant map using a quadtree representation; a means of recursively reducing the threshold values and repeating the encoding process; and a means by which refinement bits of significant coefficients are transmitted.

In accordance with yet another aspect of the instant invention there is provided method of decoding digital still images to produce a scalable, content accessible compressed bit stream comprising the steps of: decoding the bitstream header; determining the initial threshold values and the array of initial significant pixels, insignificant bits and wavelet coefficients; decoding the significance maps; modifying the significance lists and decoding the refinement bits for each threshold level; reconstruct the wavelet coefficient array; perform the inverse wavelet transform; and reconstructing the image.

Brief Description of the Drawings

Figure 1 is a schematic illustration of a three-layer wavelet decomposition.

Figure 1a is a graphic illustration of a three-layer wavelet decomposition performed on the test image "Lena".

Figure 2 illustrates the binary representation of a wavelet transform coefficient after it is converted into an integer form.

Figure 3 is a block diagram of the invented image encoder.

Figure 4 is the process of initializing the lists LSP and LIB.

Figure 5 illustrates the algorithm that determines the initial threshold.

Figure 6 is a flowchart of the quadtree coding of the significance map.

Figure 7 is a flowchart of the refinement process.

Figure 8 is a block diagram of the multiplexer.

Figure 9 illustrates the default order of data packing.

Figure 10 is a block diagram of the image decoder of the invention.

Figure 11 is a flowchart of the quadtree decoding of the significance map.

Detailed Description of Preferred Embodiments

When the wavelet transform of a preferred embodiment is applied to decompose an image it results in four frequency sub-band signals. These sub-bands are: high horizontal, high vertical or "HH", high horizontal low vertical "HL", low horizontal high vertical "LH", and low horizontal low vertical "LL", frequency sub-bands. The LL sub-band is then further wavelet-transformed to produce a further set of HH, HL, HL, and LL sub-bands. This procedure is performed recursively to produce a multi-resolution decomposition hierarchy (MDH) of the original image. This is illustrated in Fig. 1 where three levels of transformation have been applied. Of course, the skilled reader will appreciate that an arbitrary number of sub-band decompositions may be applied.

In Fig. 1 the lowest frequency sub-band i.e the sub-band that provides the coarsest resolution scale, is that at the top, left-most block 101 represented by LL3. The highest frequency sub-bands or those at the finest resolution scale are the blocks HL1 102, LH1 103, and HH1 104.

Figure 1a is a graphic illustration of the present invention's three layer wavelet decomposition of the test image Lena. The original image 1a01 can be seen to have 3 levels of resolution in the decomposed image 1a02. The high frequency data of HH1 104 can be seen to offer the most detail in the bottom, right-most block 1a03.

After a wavelet transform has occurred, each pixel is represented by a wavelet transform coefficient. In the preferred embodiment of the current invention, each of these coefficients is represented in a fixed-point, binary format, most typically with less than 16 bits, and treated as an integer. Fig. 2 illustrates the binary representation in the general case of a wavelet transform coefficient. In this system, the first bit 201 is dedicated to represent its sign -- positive or negative. The first non-zero bit 202 following the sign bit is called the leading one bit or LOB. The position of the LOB is determined by the magnitude of the coefficient. That is to say that the larger the value of the coefficient, the more closely after the sign bit will it occur. All of the bits following the LOB 202 are called refinement bits 203.

After the coefficients are generated in the wavelet transformation and are given their binary representation, three lists are initialized. The first of these is called the list of significant pixels or LSP. Each entry in LSP corresponds to an individual pixel on the MDH plane and is identified by a pair of coordinates (i,j). The LSP is initialized as an empty list since the significance of individual pixels has yet to be determined. The second list is called the list of insignificant blocks or LIB. The entries in this list are composed of the coordinates of the left-top pixel of a block of coordinates (i1,j1) plus the width and height of the block (i2,j2) measured in pixels. An entry in the LIB represents a block made up of an individual pixel when i2 = j2 = 1. When first initialized the TLIB is empty. After the lists are initialized, each sub-band block becomes an entry in LIB. The order of the entries in the initial LIB can be arranged arbitrarily but the default order of sub-band entry is LL3, LH3, HL3, HH3, LH2, HL2, HH2, LH1, HL1, HH1. Figure 4 represents the decision tree for the creation of LSP and the default entry into the LIB.

The next step in the formulation of the lists is the calculation of threshold values to determine the significance of the coefficients. After the wavelet transform, the maximum magnitude "M" of all transform coefficients must be determined. One skilled in the art is familiar with the fact that the vast majority of coefficients from an efficiently implemented MDH will have relatively low values. Once M has been determined, a value N is found which satisfies the condition: $2^N \leq M < 2^{N+1}$. The initial

threshold is set at 2^N, and the set of various N values is called the threshold index. The threshold values then decrease by powers of 2 for ease of bit-wise computation. At each threshold value a significance map is produced by comparing the coefficients with the threshold value. Those coefficients that exceed the threshold are given a value of 1 and thus join the map of significant coefficients. Coefficients less than the threshold value are given a value of zero in that significant map. A significance map for each threshold value, in the form of a binary image, is thus produced.

Recalling that the LIB is first composed of the sub-band blocks of the MDH, the preferred embodiment of the present invention, begins the quadtree encoding of the significance data. For the given block, we count the number of significant coefficients in this block. If the number is zero the identifying coordinates of this square are added to TLIB. If there is at least one significant coefficient in this block, "the parent block", it is divided into four equal-sized sub-blocks called "child blocks" and then removed from the LIB. In the event that the number of significant coefficients is one, and the size of the block is one, this entry is a single coefficient and its coordinates are moved to LSP.

There are two methods available to process the sub-blocks. The first method, known as depth-first quadtree coding, inserts the four sub-blocks into LIB immediately following the position of their parent block. The four child blocks are then evaluated immediately with respect to their significance and this operation is applied recursively until no more subdivision is possible. When all significant coefficients in this block are found and moved into LSP, the coding of the present entry is completed. The process then moves to the next block in the LIB.

The second method, or breadth-first quadtree coding, adds these four sub-blocks to the end of LIB where they are evaluated before the same pass ends. With the breadth-first process, all parent squares at the same level will be processed before any blocks of the next generation.

After all entries in the present LIB have been processed at one level of significance, the entries in TLIB are reordered according to the size of the block: each block must be put before those blocks with larger size so that it can be processed first for the next threshold. Most pixels adjacent to significant pixels have been moved into TLIB as pixel level entries if not significant to the present threshold. Due to the correlation of adjacent coefficients, it is very likely that these adjacent pixels will be significant at the next threshold level. In the event of a strict bit budget, we must put these pixel level blocks first to ensure that precious bits are not used to find significant coefficients from big blocks, and risk missing pixel level significant coefficients. The reordering of TLIB will therefore aid the encoding of more significant coefficients using fewer bits. While not essential, experiments show that higher PSNR will be achieved using this reordering scheme. The final step in this quadtree process is to replace the LIB with TLIB for subsequent scanning at the next level of significance and to reset TLIB to empty. Before moving to the next threshold however, the refinement data for significant coefficients is collected.

Figure 7 illustrates the refinement pass, in the quadtree encoding of the image data. For those coefficient entries of LSP that are significant at threshold $2^{N+1}(|c_{i,j}| \geq 2^{N+1})$, output its *N-th* bit. As illustrated in Figure 3 and discussed above, following the refinement pass, the threshold is divided by 2 and the above process resumes with the new LIB --formerly the TLIB -- and the new threshold value.

The arithmetic coding of the bit stream produced by the above process is not essential. There are two types of data in the bit-stream: quadtree-coded significance map encoding bits and refinement bits, which form a completely embedded code. There are many ways to organize this bitstream. In theory, the significance map data and the refinement bits data can be merged together in any order. This is handled by a multiplexer which packs the data according to user-specified priority. The default order of data packing is illustrated in Figure 9 and ensures optimum results when high PSNR is pursued.

At the first stage of decoding, the following information must be reconstructed from the header bits: the starting threshold index N, the number of wavelet scales, and the image size. Based on the above information, we can initialize and fill LIB while the initial LSP and TLIB are set empty. The initial value of all wavelet coefficients is set to zero.

The key process of decoding is illustrated in Figure 11, in which the significance map at a given threshold level is decoded based on the received bits. Assuming the present threshold index is *N*, the process first loads an entry from the LIB and reads one bit from the bitstream. If the bit value is zero, this entry is moved to TLIB. In the alternative, the entry is checked to determine if its size is one. If the entry is a single pixel, then update the wavelet coefficient at the current position as $2^N + 2^{N-1}$, and read in one more bit. If this bit is a 1, update the coefficient at this position as $-(2^N + 2^{N-1})$. The entry is then moved into the LSP. If the entry is not at pixel level, the process decomposes it into four equal sized sub-blocks. If the encoder has used the depth-first method (this decision having been made by the encoder and which information is contained in the header part of the bitstream), insert the sub-blocks into LIB at its parent block position. If the encoder has used the breadth-first method, add the sub-blocks to the end of LIB. After all entries in LIB have been decoded, using TLIB to replace LIB, which will be processed at the next threshold level. The LIB is reordered according to the same rule as in encoding, and the TLIB is reset as empty.

In the refinement pass of the decoding, all coefficients, which have been moved into LSP, are updated according to following rule: if the coefficient is negative, then add 2^{N-1} if received bit is 0, or subtract 2^{N-1} if received bit is 1. On the contrary, if the coefficient is positive, then add 2^{N-1} if received bit is 1, or subtract 2^{N-1} if received bit is 0.

At any point in the encoding or decoding process of the present invention, bit consumption may be calculated to determine if the bit budget has been exceeded and the process may be halted. In this manner, precise bit rate control can be easily

achieved if there is no arithmetic coding on the bit stream. With arithmetic coding, the resultant bitstream is usually shorter than the desired length.

CLAIMS

WE CLAIM

1. A method for encoding and decoding digital still images to produce a scalable, content-accessible-compressed-bit-stream comprising the steps:

   decomposing and ordering the raw image data into a hierarchy of multi-resolution sub-images;

   setting an initial threshold of significance and creating a significance index;

   determining an initial list of insignificant blocks;

   forming the list of significant coefficients by encoding a significant map using a quadtree representation;

   recursively reducing the threshold values and repeating the encoding process for each threshold value; and

   transmitting refinement bits of significant coefficients.

2. The method defined in claim 1, wherein the hierarchy of multi-resolution sub-images are composed on the basis of a wavelet transformation.

3. The method defined in claim 1, wherein the hierarchy of multi-resolution sub-images are composed on the basis of a Fourier-based transformation.

4. The method defined in claim 1, wherein the hierarchy of multi-resolution sub-images are composed using raw image data.

6. The method defined in claim 1, further comprising the step of a multiplexing protocol that assembles the compressed data from different region and resolution channels into an integrated bit-stream enabling both the encoder and the decoder to selectively and interactively control the bit budget and the quality of the compressed images.

7. An apparatus for encoding and decoding of digital still images that produces a scalable, content accessible compressed bit stream comprising:

   a means of decomposing and ordering the raw image data into a hierarchy of multi-resolution sub-images;

   means for setting an initial threshold of significance and creating a significance index;

   means for determining an initial list of insignificant blocks;

   means of forming the list of significant coefficients by encoding a significant map using a quadtree representation;

a means of recursively reducing the threshold values and repeating the encoding process; and

transmitting refinement bits of significant coefficients.

8. The apparatus defined in claim 7, wherein the hierarchy of multi-resolution sub-images are composed using a wavelet transformation.

9. The apparatus defined in claim 7, wherein the hierarchy of multi-resolution sub-images are composed using a Fourier-based transformation.

10. The apparatus defined in claim 7, wherein the hierarchy of multi-resolution sub-images are composed using raw image data.

11. The apparatus defined in claim 7, further comprising a multiplexing means that assembles the compressed data from different region and resolution channels into an integrated bit-stream enabling both the encoder and the decoder to selectively and interactively control the bit budget and the quality of the compressed images.

12. A method of decoding digital still images to produce a scalable, content accessible compressed bit stream comprising the steps:

decoding the bitstream header;

determining the initial threshold values and the array of initial significant pixels, insignificant bits and wavelet coefficients;

decoding the significance maps;

modifying the significance lists and decoding the refinement bits for each threshold level;

reconstruct the wavelet coefficient array;

perform the inverse wavelet transform; and

reconstruct the image.

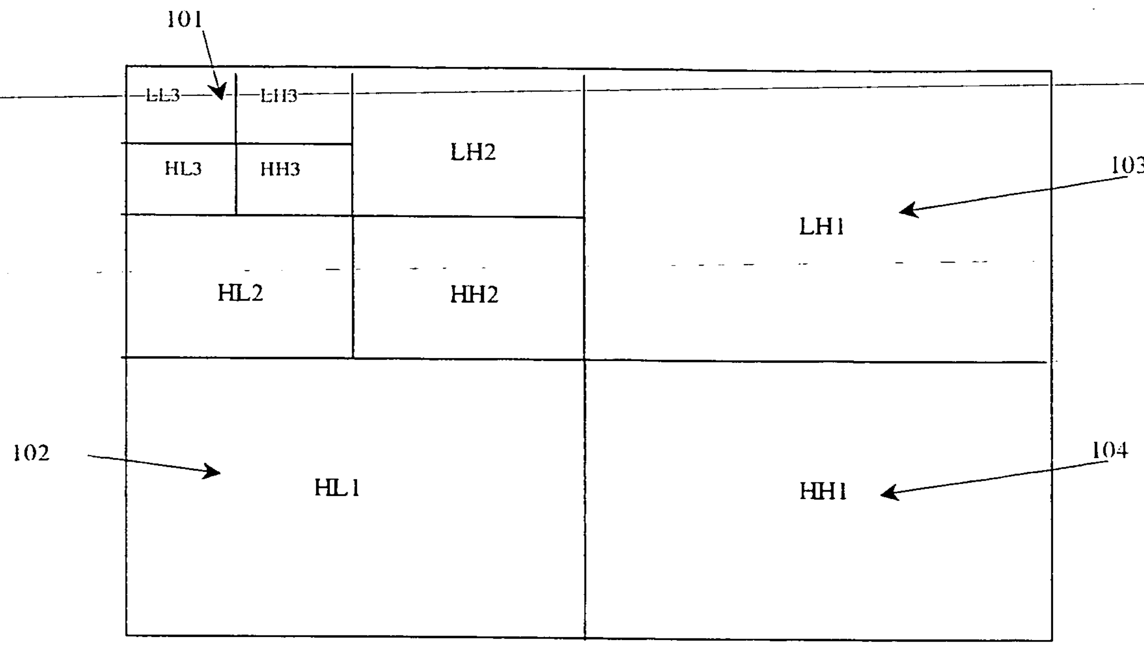

Figure 1.

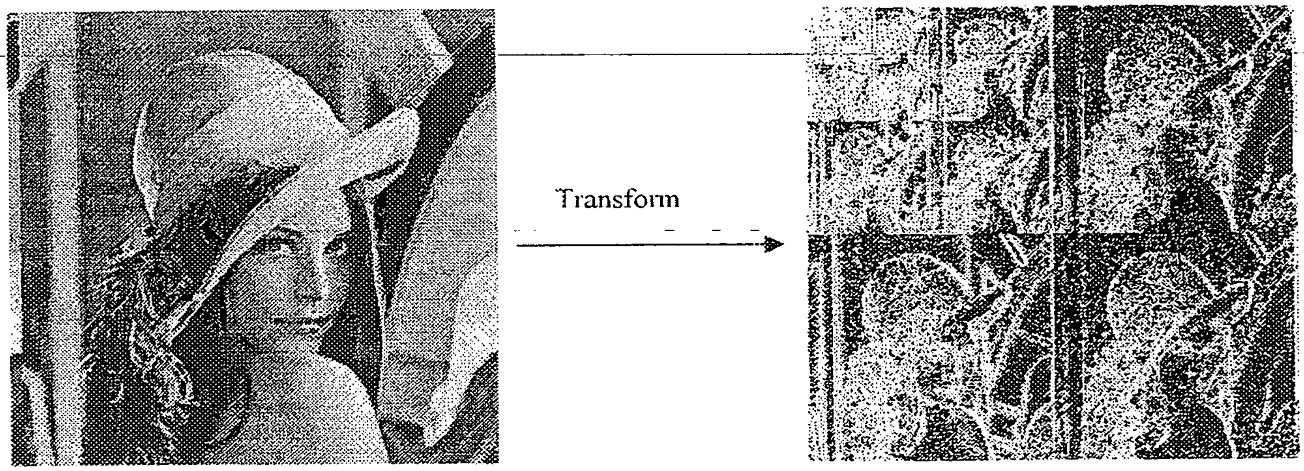

Figure 1a

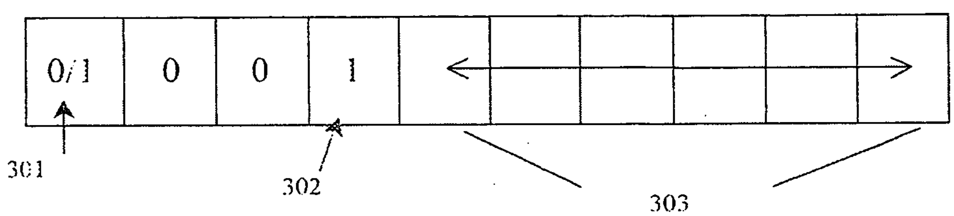

Figure 2

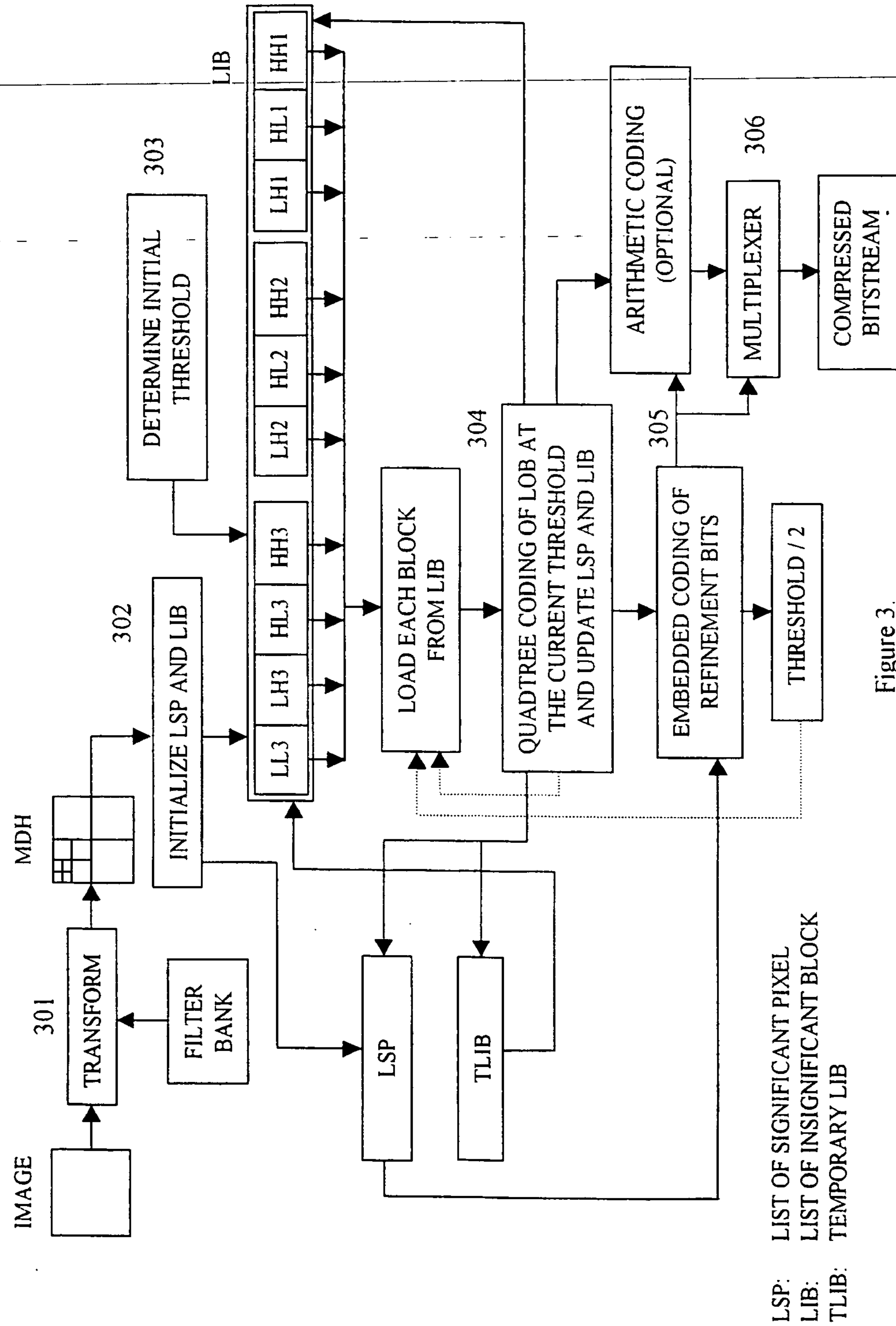
IMAGE
301
TRANSFORM
FILTER BANK
MDH
302
INITIALIZE LSP AND LIB
303
DETERMINE INITIAL THRESHOLD
LIB
LL3
LH3
HL3
HH3
LH2
HL2
HH2
LH1
HL1
HH1
LOAD EACH BLOCK FROM LIB
304
QUADTREE CODING OF LOB AT THE CURRENT THRESHOLD AND UPDATE LSP AND LIB
305
EMBEDDED CODING OF REFINEMENT BITS
THRESHOLD / 2
ARITHMETIC CODING (OPTIONAL)
306
MULTIPLEXER
COMPRESSED BITSTREAM
LSP
TLIB
LSP: LIST OF SIGNIFICANT PIXEL
LIB: LIST OF INSIGNIFICANT BLOCK
TLIB: TEMPORARY LIB

Figure 3.

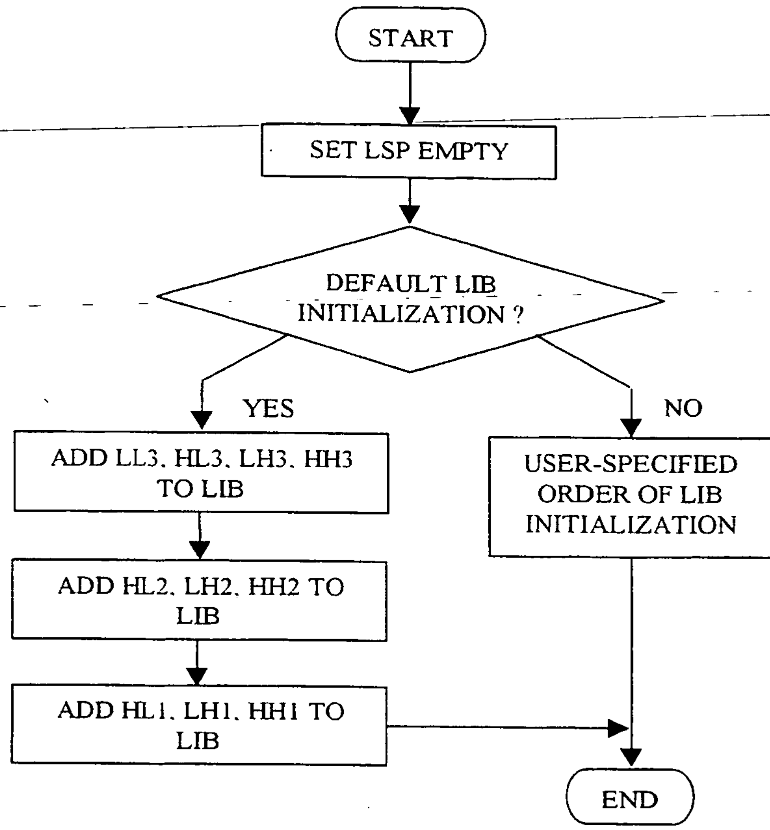

Figure 4.

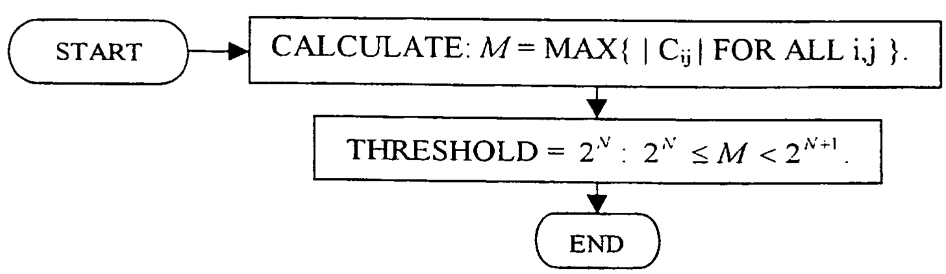

Figure 5.

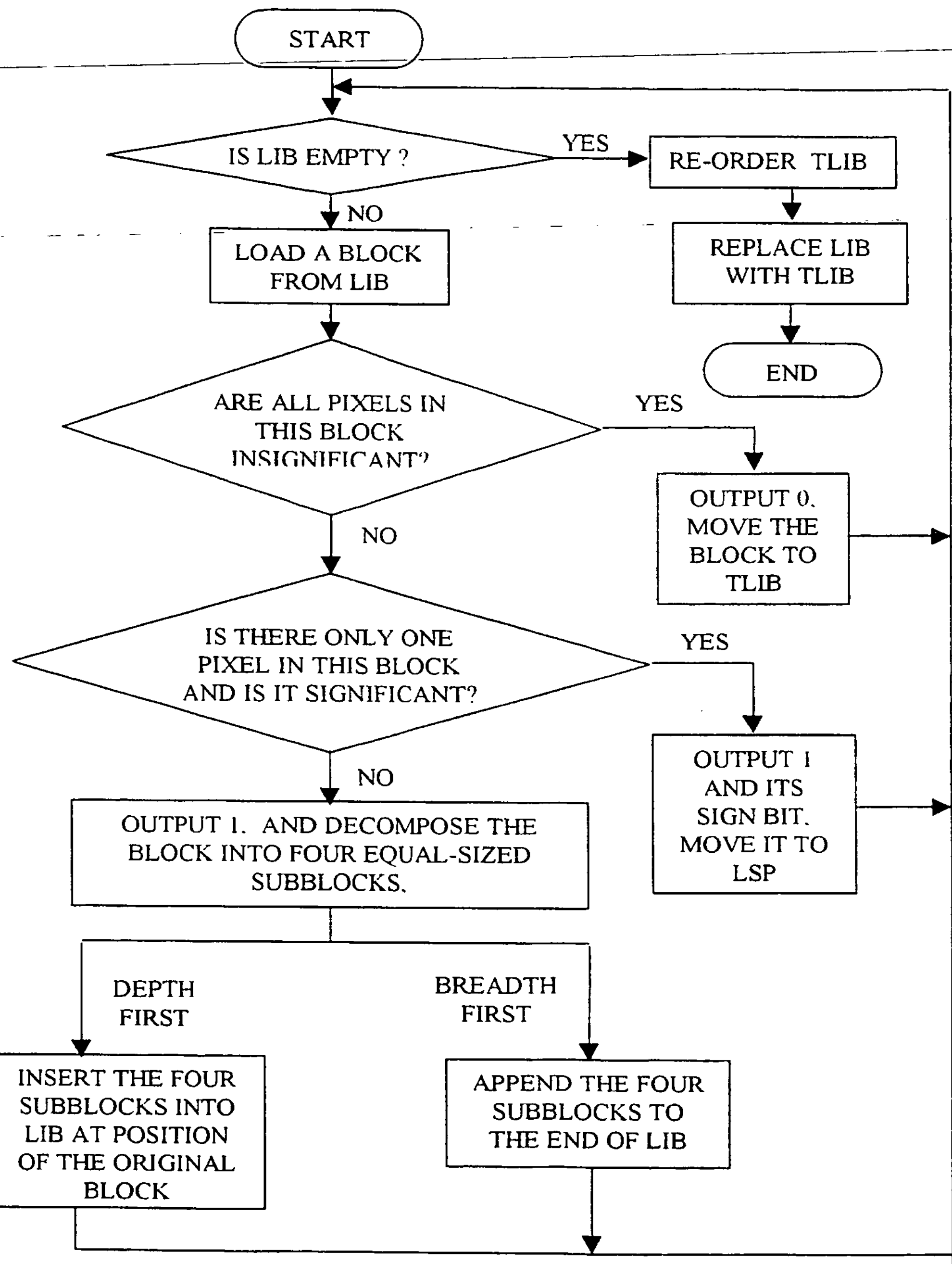
START
IS LIB EMPTY ?
YES
RE-ORDER TLIB
NO
LOAD A BLOCK FROM LIB
REPLACE LIB WITH TLIB
END
ARE ALL PIXELS IN THIS BLOCK INSIGNIFICANT?
YES
OUTPUT 0, MOVE THE BLOCK TO TLIB
NO
IS THERE ONLY ONE PIXEL IN THIS BLOCK AND IS IT SIGNIFICANT?
YES
OUTPUT 1 AND ITS SIGN BIT, MOVE IT TO LSP
NO
OUTPUT 1, AND DECOMPOSE THE BLOCK INTO FOUR EQUAL-SIZED SUBBLOCKS.
DEPTH FIRST
BREADTH FIRST
INSERT THE FOUR SUBBLOCKS INTO LIB AT POSITION OF THE ORIGINAL BLOCK
APPEND THE FOUR SUBBLOCKS TO THE END OF LIB

Figure 6.

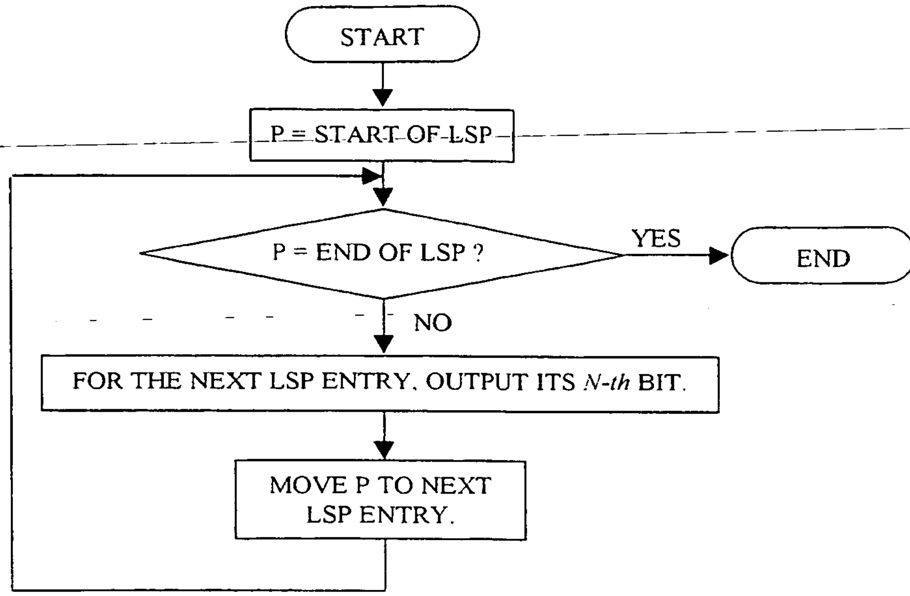

Figure 7.

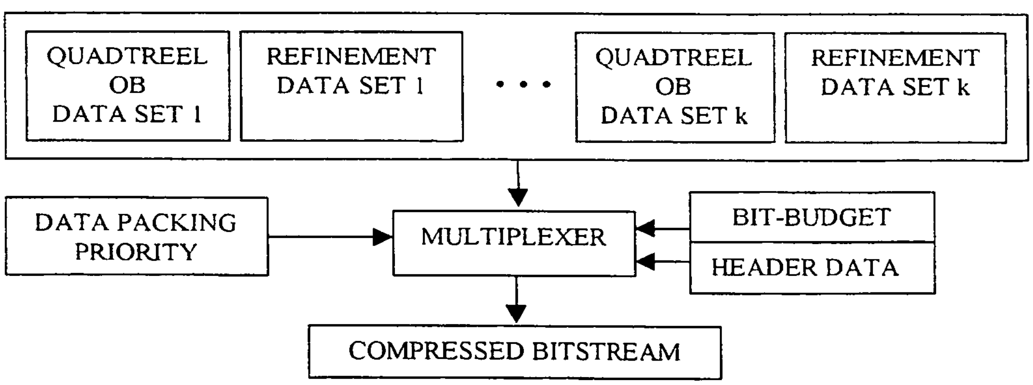

Figure 8.

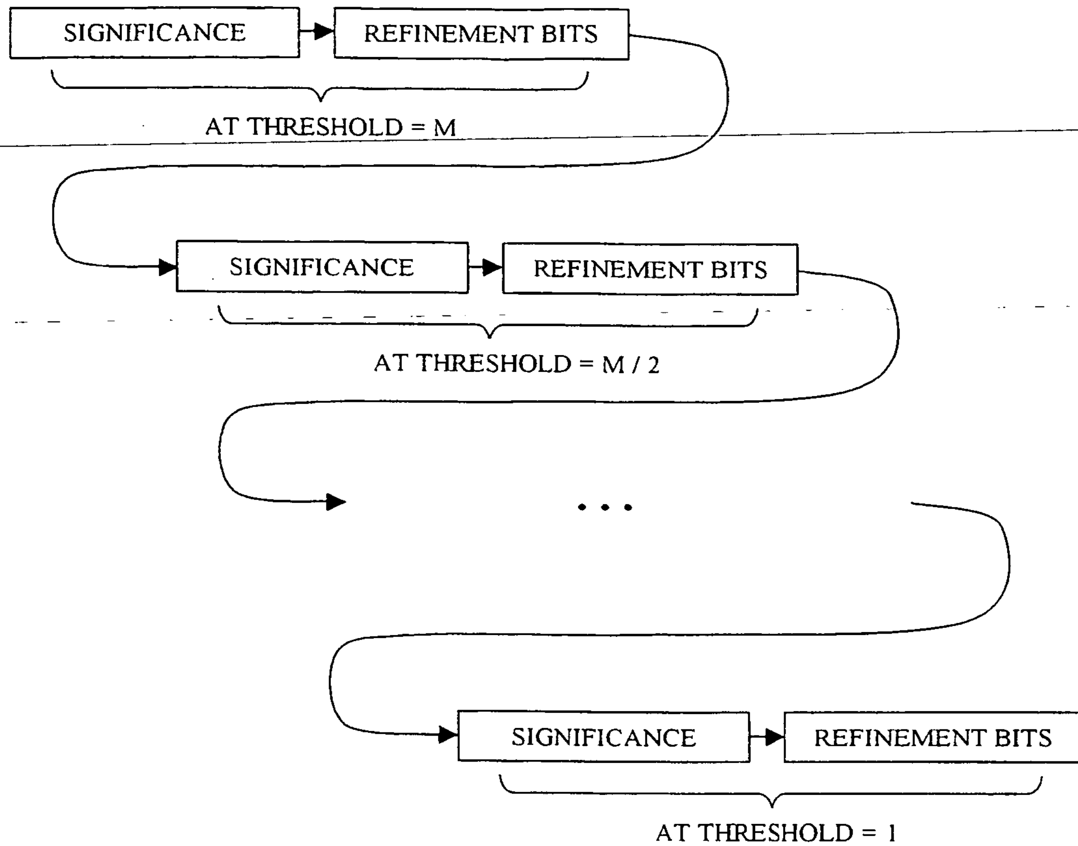
SIGNIFICANCE
REFINEMENT BITS
AT THRESHOLD = M
SIGNIFICANCE
REFINEMENT BITS
AT THRESHOLD = M / 2
. . .
SIGNIFICANCE
REFINEMENT BITS
AT THRESHOLD = 1

Figure 9.

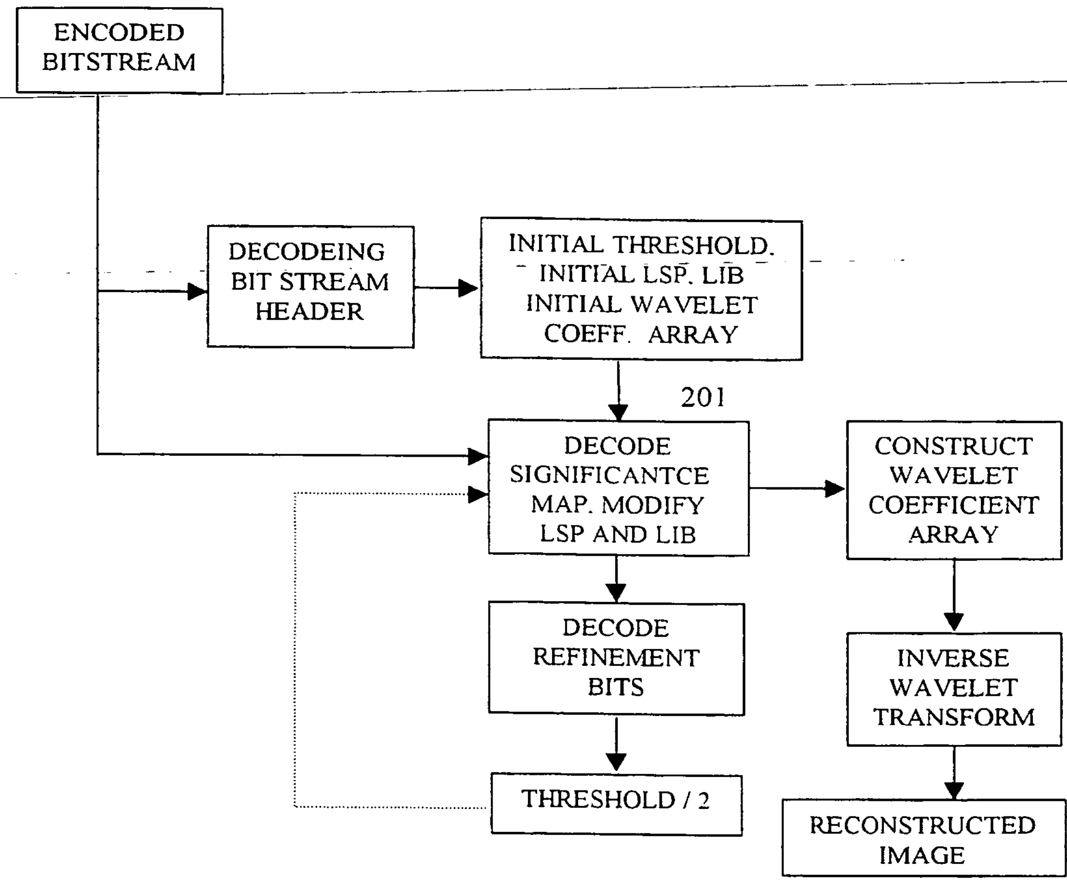
ENCODED BITSTREAM
DECODEING BIT STREAM HEADER
INITIAL THRESHOLD, INITIAL LSP, LIB INITIAL WAVELET COEFF. ARRAY
201
DECODE SIGNIFICANTCE MAP. MODIFY LSP AND LIB
CONSTRUCT WAVELET COEFFICIENT ARRAY
DECODE REFINEMENT BITS
INVERSE WAVELET TRANSFORM
THRESHOLD / 2
RECONSTRUCTED IMAGE

Figure 10.

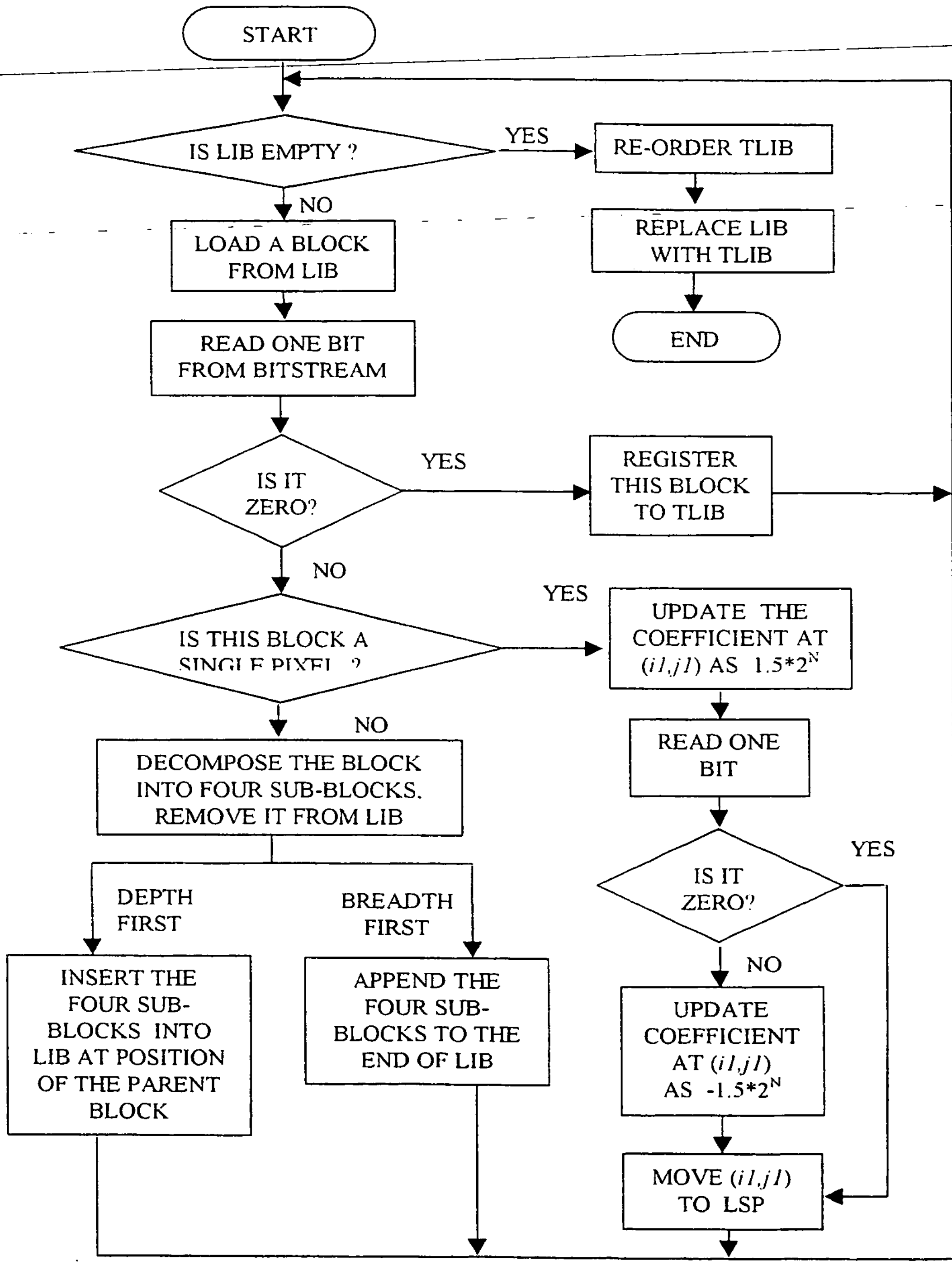
START
IS LIB EMPTY ?
YES
RE-ORDER TLIB
REPLACE LIB WITH TLIB
END
NO
LOAD A BLOCK FROM LIB
READ ONE BIT FROM BITSTREAM
IS IT ZERO?
YES
REGISTER THIS BLOCK TO TLIB
NO
IS THIS BLOCK A SINGLE PIXEL ?
YES
UPDATE THE COEFFICIENT AT (i1,j1) AS 1.5*2^N
READ ONE BIT
IS IT ZERO?
YES
NO
UPDATE COEFFICIENT AT (i1,j1) AS -1.5*2^N
MOVE (i1,j1) TO LSP
NO
DECOMPOSE THE BLOCK INTO FOUR SUB-BLOCKS. REMOVE IT FROM LIB
DEPTH FIRST
BREADTH FIRST
INSERT THE FOUR SUB-BLOCKS INTO LIB AT POSITION OF THE PARENT BLOCK
APPEND THE FOUR SUB-BLOCKS TO THE END OF LIB

Figure 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 99/00739

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T9/40

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BANHAM M R ET AL: "A WAVELET TRANSFORM IMAGE CODING TEHNIQUE WITH A QUADTREE STRUCTURE" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON ACOUSTICS, SPEECH AND SIGNAL PROCESSING (ICASSP),US,NEW YORK, IEEE, vol. CONF. 17, page IV-653-IV-656 XP000467279 ISBN: 0-7803-0532-9 abstract page 654, paragraph 3	1,2,4,7, 8,10,12
A	US 5 764 807 A (SAID AMIR ET AL) 9 June 1998 (1998-06-09) abstract column 5, line 65 -column 6, line 5	1,2,4,7, 8,10,12

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 November 1999	03/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	González Arias, P

1

Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/CA 99/00739

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GIJBELS T ET AL: "AN ASIC-ARCHITECTURE FOR VLSI-IMPLEMENTATION OF THE RBN-ALGORITHM" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON PATTERN RECOGNITION,US,LOS ALAMITOS: IEEE COMP. SOC. PRESS, vol. CONF. 10, page 408-412 XP000166513 ISBN: 0-8186-2062-5 page 410, paragraph 2	6

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

In ational Application No
PCT/CA 99/00739

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5764807 A	09-06-1998	NONE	